(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 139 010**
A1

(12) # EUROPEAN PATENT APPLICATION

published in accordance with Art. 158(3) EPC

(21) Application number: **84900887.5**

(22) Date of filing: **27.02.84**

Data of the international application taken as a basis:

(86) International application number:
PCT/JP84/00068

(87) International publication number:
WO84/03779 (27.09.84 84/23)

(51) Int. Cl.⁴: **G 05 B 11/36**
G 05 D 3/00

(30) Priority: **16.03.83 JP 42309/83**

(43) Date of publication of application:
02.05.85 Bulletin 85/18

(84) Designated Contracting States:
DE FR GB

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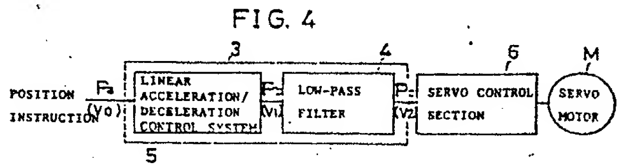
(54) **METHOD OF CONTROLLING ACCELERATION AND DECELERATION.**

(57) A method of generating a speed command signal which is delivered to a servo motor control unit in a position control apparatus. A given position command signal is applied to a low-pass filter (4) either directly or through a linear acceleration/deceleration unit (3). An output of the low-pass filter (4) is employed as a speed command signal delivered to a control unit (6) for a servo motor (M).

FIG. 4



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SPECIFICATION

ACCELERATION/DECELERATION CONTROL SYSTEM

Technical Field

The present invention relates to an acceleration/deceleration control system of a servo motor used in an NC machine tool and a robot.

Background Art

Fig. 1 is a block diagram of a servo motor acceleration/deceleration control system. A typical example of the conventional acceleration/deceleration system of this type is an exponential acceleration/deceleration control system.

In this system, an exponential function type acceleration/deceleration control unit is used as an acceleration/deceleration control section 1 shown in Fig. 1. When a position instruction is supplied as a displacement V_0 per unit time to the acceleration/deceleration section 1, i.e., when a pulsed input shown in Fig. 2(a) is entered as a value V_0 which is substantially the same as the velocity, an exponential output shown in Fig. 2(b) is obtained.

As shown in this response waveform, an acceleration speed is high at a leading edge (indicated by α in Fig. 2) due to the influence of a high-frequency component, so that a servo control section 2 and a load system are subjected to shock, resulting in vibrations. As shown in Fig. 2(b), a long period of time is required to decelerate and stop the servo motor, resulting in inconvenience. For these reasons, for example, when X- and Y-axis servo motors are used to shift a table of a machine tool in an arcuated manner, the table has a locus smaller than that designated by an instruction.

A linear acceleration/deceleration control system can be used in place of the exponential acceleration/deceleration control system. An output waveform shown in Fig. 5(b) is obtained in response to a step

input shown in Fig. 5(a). As indicated by this output waveform, an acceleration speed abruptly changes, and a servo control system and a load system are subjected to shock, resulting in vibrations. For example, an arm of a robot or the like continues to vibrate when it is stopped quickly, resulting in inconvenience.

Furthermore, since the servo control system and the load system have natural frequencies, when the servo control system and the load system are driven by frequency components similar to the natural frequencies, respectively, the servo control system and the load system vibrate by themselves. For this reason, vibration of the natural frequency components included in position instruction for the servo control system and the load system must be cut off.

Disclosure of Invention

A transfer function in an exponential acceleration/deceleration control section for generating the output shown in Fig. 2(b) in response to the step input shown in Fig. 2(a) is a transfer function H(S) having a time-lag of first order as follows:

$$H(S) = K/(S + K) \qquad \ldots(1)$$

where K is a constant.

This transfer function is obtained by a first-order low-pass filter. The conventional acceleration/deceleration control section 1 given by this transfer function indicates that a low-frequency component included in the position instruction (input) passes through but a high-frequency component is cut off, and that the resultant frequency component as the position instruction is supplied to the servo control section 2. However, as indicated by the output waveform shown in Fig. 2(b), the influence of a high-frequency component occurs at the leading edge or the like to cause an abrupt change in velocity. For this reason, in order to cut off the high-frequency component, a time constant of the transfer function

given by equation (1) must be increased. However, when the time constant is increased, a response time becomes slow, and a time for stopping the servo motor becomes prolonged.

This can be overcome by using a higher-order low-pass filter in place of the first-order low-pass filter. In this case, the position instruction to the servo motor is filtered through this higher-order low-pass filter, and the servo motor is driven by the filtered component. As the low pass filter has a higher order, the natural frequencies of the servo control system and the load system can be cut off, and the high-frequency component is also cut off. As a result, a smooth response waveform and a fast response can be obtained.

It is, therefore, a first object of the present invention to provide an acceleration/deceleration control system of a servo motor, wherein a change in velocity can be decreased by using a higher-order low-pass filter, and a short response time can be obtained with a small delay.

It is a second object of the present invention to provide an acceleration/deceleration system of a servo motor wherein no vibrations occur and the servo motor can be operated with a small change in velocity.

In order to achieve the above objects of the present invention, there is provided an acceleration/deceleration system for controlling acceleration/deceleration of a servo motor by filtering a position instruction to the servo motor through a low-pass filter of second or higher order.

According to the acceleration/deceleration control system for controlling linear acceleration/deceleration, the position instruction supplied to the servo motor is subjected to linear acceleration/deceleration control. The linearly controlled instruction is

filtered through a low-pass filter of second or higher order.

As described above, since the position instruction is supplied to the servo motor through the low-pass filter of second or higher order, the high-frequency component is cut off, and the natural frequency components of the servo control system and the load system are also cut off. As a result, the servo control system and the load system will neither be subjected to shock nor generate vibrations. In addition, the servo control system and the load system will not vibrate by themselves. Since a high-order low-pass filter is used, a fast response time can be obtained. For example, unlike the conventional example, a table or the like of a machine tool will not trace a locus smaller than that specified by the instruction even if it is driven in an arcuated locus.

Brief Description of Drawings

Fig. 1 is a block diagram of an acceleration/deceleration control system of a servo motor, Fig. 2 shows waveforms of an input and an output with respect to a conventional exponential acceleration/deceleration control system, Fig. 3 shows input/output waveforms with respect to the acceleration/deceleration control section when a higher-order low-pass filter is used in this section, Fig. 4 is a block diagram of an embodiment of the present invention when a higher-order low-pass filter is used, Fig. 5 shows input/output waveforms of the respective blocks of the embodiment shown in Fig. 4, Fig. 6 is a block diagram of a linear acceleration/deceleration control system, Fig. 7 shows input/output waveforms with respect to the system shown in Fig. 6, Fig. 8 is a block diagram of a first-order digital filter, Fig. 9 is a block diagram of a second-order digital filter, Fig. 10 is a block diagram of a third-order digital filter, and Fig. 11 is a flow chart for explaining an operation of the present

invention when the third-order digital filter is coupled to the linear acceleration/deceleration control section.

Best Mode of Carrying Out the Invention

The present invention will be described in detail hereinafter.

Transfer functions H(S) of a higher-order low pass filter can be obtained by a second-order transfer function, a third-order transfer function as a combination of first- and second-order transfer functions, and a fourth-order transfer function as a combination of second-order transfer functions in the following manner:

$$\text{2nd-order } H(S) = (A_1W_0)^2/\{S^2 + (A_1W_0/Q_1)S + (A_1W_0)^2\} \quad \ldots(2)$$

$$\text{3rd-order } H(S) = \{(B_1W_0)/(S + B_1W_0)\} \times [(A_1W_0)^2/\{S^2 + (A_1W_0/Q_1)S + (A_1W_0)^2\}] \quad \ldots(3)$$

$$\text{4th-order } H(S) = [(A_1W_0)^2/\{S^2 + (A_1W_0/Q_1)S + (A_1W_0)^2\}] \times [(A_2W_0)^2/\{S^2 + (A_2W_0/Q_2)S + (A_2W_0)^2\}] \ldots(4)$$

where A_1, A_2, B_1, Q_1 and Q_2 are coefficients and W_0 is the angular velocity at a cutoff frequency of the filter.

By properly selecting the coefficients (i.e., A_1, B_1 and Q_1) of the transfer functions H(S), a low-pass filter having a high speed and smooth response and free from vibrations can be obtained. This low-pass filter may be any one of Bessel, Butterworth and Chebyshev filters.

An optimal low-pass filter for achieving the above objects of the present invention can be obtained such that the coefficients of the Bessel filter are properly selected, and a cutoff frequency of the filter is selected to cut off the natural frequencies of the servo control system and the load system. This Bessel

low-pass filter is used as the acceleration/deceleration control section 1 in Fig. 1. An output shown in Fig. 3(b) is generated from the acceleration/deceleration section 1 in response to the input waveform of the position instruction, as shown in Fig. 3(a). In this manner, the high-frequency component is cut off from the position instruction, so that a change in output V_1 is smooth. A high acceleration speed at the leading edge of the output will not be obtained. As a result, the time required for decelerating and stopping the servo motor can be shortened.

As a second embodiment of the present invention, a high-order low-pass filter 4 is connected to an output of a linear acceleration/deceleration section 3, as shown in Fig. 4. An output from the low-pass filter 4 drives a servo control section 6 and a servo motor M. This output V_2 becomes smooth, as shown in Fig. 5(c). More particularly, when a pulsed input V_0 shown in Fig. 5(a) is supplied to the linear acceleration/deceleration section 3, the linear acceleration/deceleration section 3 generates an output V_1, as shown in Fig. 5(a). In the conventional control system, the output V_1 is supplied to the servo control section 6. However, according to the present invention, the output V_1 is supplied to the high-order low-pass filter 4 which then generates the output V_2 whose waveform is illustrated in Fig. 5(c). The output V_2 is then supplied to the servo control section 6. As a result, since the output V_2 whose waveform shown in Fig. 5(c) is smoother than that of the output V_1 shown in Fig. 5(b) is supplied to the servo control section 6, the servo control section 6 and the servo motor M will not receive shock caused by an abrupt change in velocity and will not generate vibrations. In addition, the servo control section 6 and the servo motor M have a fast response time.

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As described above, the low-pass filter is used in the acceleration/deceleration control section according to the present invention. In the linear acceleration/deceleration system, the linear acceleration/deceleration section 3 and the low-pass filter 4 constitute an acceleration/deceleration control section 5. As a result, an acceleration/deceleration control system having a fast response time and being free of vibrations can be obtained.

An embodiment of the present invention which has the acceleration/deceleration control section 5 consisting of the linear acceleration/deceleration section 3 and the low-pass filter 4 will be described with reference to the accompanying drawings.

Digital processing of the linear acceleration/deceleration section 3 will be described with reference to Fig. 6. A position instruction Pa for each axis is supplied from an interpolation distribution control section or the like to the linear acceleration/deceleration section 3 for each sampling (a sampling period T). The linear acceleration/acceleration section 3 has (n - 1) delay units Z^{-1} (delay of the sampling period T) (where n is a value obtained by dividing by the sampling period T an acceleration/deceleration time from the beginning to the end of acceleration or deceleration, i.e., $n = \tau/T$). The position instruction Pa is added by an adding means 10 to the output from each of the delay units Z^{-1}. A multiplying means 11 multiplies 1/n with a sum from the adding means 10, thus obtaining Pb as follows:

$$Pb = (Pa + X_1 + X_2 + \ldots + X_{n-1})/n \qquad \ldots(5)$$

For example, if the position instruction Pa, the sampling period T and the acceleration/deceleration time are given as 100, 8 msec and 40 msec, respectively, n = 40/8 = 5. The linear acceleration/deceleration section 3 comprises four delay units Z^{-1}, and the relationship between the input and the

output is shown in Figs. 7(a) and 7(b). In the first sampling cycle,

$Pa = 100$, and X_1 to $X_4 = 0$,

therefore,

$$Pb = (Pa + X_1 + X_2 + X_3 + X_4)/n$$
$$= 100/5 = 20$$

In the second sampling cycle,

$Pa = 100$, $X_1 = 100$ and X_2 to $X_4 = 0$

therefore,

$$Pb = (100 + 100)/5 = 40$$

Similarly, in the third sampling cycle, Pb = 60 is obtained; in the fourth sampling cycle, Pb = 80; in the fifth sampling cycle, Pb = 100. In this manner, Pb is linearly increased. When the input Pa becomes zero, as shown in Fig. 7(a), the output Pb is also linearly decreased.

The linear acceleration/deceleration section 3 is operated as follows.

The high-order digital low-pass filter 4 will be described. This filter 4 can be prepared by a combination of the first- and/or second-order elements. The transfer function of the first-order filter is given by equations (1) and (3) in the following manner:

$$H(S) = BW_0/(S + BW_0)$$

This transfer function is Z-transformed to obtain a pulse transfer function as follows:

$$H(Z) = G/(1 - K \cdot Z^{-1})$$

This pulse transfer function is achieved by the circuit shown in Fig. 8.

Referring to Fig. 8, reference numeral 12 denotes a multiplying means; and 13, an adding means. Reference symbol Z^{-1} denotes a delay unit for delaying an input by one sampling period T. Reference symbols K and G are values given as follows:

$$K = e^{-BW_0 T}$$
$$G = 1 - K$$

where B is the filter coefficient and W_0 is the angular velocity at the cutoff frequency f_0 of the filter, i.e., $W_0 = 2\pi f_0$.

When the operation of the circuit shown in Fig. 8 is performed for every sampling period T, a first-order digital filter can be obtained. In other words, the operations are performed as follows to obtain Y_0:

$Y_1 = Y_0$ (Y_1 is the immediately preceding sampled value of a sampled value Y_0)

$Y_0 = G \cdot X + K \cdot Y_1$

The sample value Y_0 from the first-order filter is an output therefrom.

Similarly, a Z-transformed pulse transfer function of the second-order transfer function H given by equation (2) is derived as follows:

$$H(Z) = G/(1 - K \cdot Z^{-1} - L \cdot Z^{-2})$$

This transfer function is achieved by a circuit shown in Fig. 9. The following operations are performed for every sampling period T so as to obtain an output Y_0, thereby obtaining a second-order digital filter.

$Y_2 = Y_1$ (Y_2 is the immediately preceding sampled value of the sampled value Y_1)

$Y_1 = Y_0$ (Y_1 is the immediately preceding sampled value of the sampled value Y_0)

$Y_0 = G \cdot X + K \cdot Y_1 + L \cdot Y_2$

for $K = 2 \cdot e^{-AW_0T/2Q} \cdot \cos(AW_0T\sqrt{4Q^2 - 1}/2Q)$

$L = -e^{-AW_0T/Q}$

$G = 1 - K - L$

When the circuits shown in Figs. 8 and 9 are connected in series in consideration of the orders of the filters, the third- and fourth-order digital low-pass filters given by equations (3) and (4) can be obtained. Additional filters shown in Figs. 8 or 9 are selectively connected to obtain a higher order digital low-pass filter.

For example, in order to obtain a third-order

filter, an output from the circuit shown in Fig. 8 is supplied to the circuit shown in Fig. 9. In other words, the first- and second-order filter operations are successively performed as follows:

$$Y_1 = Y_0$$
$$Y_0 = G_1 \cdot X + K_1 \cdot Y_1$$
$$Z_2 = Z_1$$
$$Z_1 = Z_0$$
$$Z_0 = G2 \cdot Y_0 + K_2 \cdot Z_1 + L_2 \cdot Z_2$$

The output Z_0 is thus obtained from the third-order digital filter.

The standard values of the respective coefficients Q, A and B in the Bessel filter are given below:

For the second-order filter:

Q = 0.5774 and A = 1.732

For the third-order filter:

Q = 0.6911, A = 2.542 and B = 2.322

For the fourth-order filter:

Q_1 = 0.5219, A_1 = 3.023, Q_2 = 0.8055 and A_2 = 3.389

When the values of the coefficients Q, A and B (especially the value of coefficient Q) are changed, a filter which does not overshoot in response to the step input can be obtained.

Another embodiment will be described wherein the low-pass filter 4 is coupled to the output of the linear acceleration/deceleration section 3 shown in Fig. 4. The linear acceleration/deceleration control shown in Fig. 6 is performed, and a resultant output is processed by the three-order low-pass filter shown in Fig. 10 under the control of a microprocessor or the like. This operation will be described with reference to a flow chart shown in Fig. 11.

The coefficients Q, A and B of the Bessel third-order filter, the cutoff frequency f_0 of this filter, the sampling period T and the time interval for which acceleration/deceleration is started and

continues until a preset value is obtained are preset to obtain the respective coefficients K_1, G_1, K_2, L_2, G_2 and n (= τ/T). The obtained values are entered in a microprocessor for controlling a robot or a machine tool (the respective coefficients K_1, G_1, K_2, L_2 and G_2 may be calculated by the microprocessor). The processing shown in Fig. 11 is performed for every sampling period T.

When the position instruction Pa for each axis which is calculated by an interpolating means is supplied to the linear acceleration/deceleration section 3 for every sampling period T, the operation shown in Fig. 6 and given by equation (5) is performed. More specifically, the input value Pa and each of the delayed values X_1 to X_{n-1} stored in the memory are added. The resultant sum is divided by n. The obtained value Pb is then stored in the memory (step 101). At the same time, the memory contents for the values X_1 to X_{n-1} are shifted (steps 102-1 to 102-N-2) in such a manner that the value of X_{n-2} is stored in a memory area for X_{n-1} (step 102-1), the value of X_{n-3} is stored in a memory area for X_{n-2} (step 102-2),... the value of X_1 is stored in a memory area for X_2 (step 102-N-2), and the input Pa is stored in a memory area for X_1 (step 103). This processing is the linear acceleration/deceleration processing F_1.

The third-order low-pass filter processing F_2 is then performed. Stored data from the memory area for Y_0 is shifted to the memory area for Y_1 (step 104). By using the value Pb obtained by the linear acceleration/deceleration processing F_1 and the value Y_1, the following operation is performed:

$$Y_0 = G_1 \, Pb + K_1 \, Y_1$$

The resultant vlaue of Y_0 is stored in the memory (step 105). The values stored in the memory areas for Z_2 and Z_1 are updated to the values stored in the memory areas for Z_1 and Z_0 (steps 106 and 107). The following step

is executed, and the resultant value of Z_0 is stored (step 108).

$$Z_0 = G_2 Y_0 + K_2 Z_1 + L_2 Z_2$$

The value stored in the memory area for Z_0 is generated as Pc (step 109).

When the processing F_1 and the processing F_2 are executed for every timing period, the output Pb from the linear acceleration/deceleration section 3 in response to the input Pa is shown in Fig. 5(b), and the output Pc from the low-pass filter 4 is given as a smooth waveform signal, as shown in Fig. 5(c). The output Pc is supplied to the servo control section 6, high-speed acceleration/deceleration control can be performed without subjecting the servo control section 6, the servo motor M and the like to shock.

In the embodiment described with reference to the flow of Fig. 11, the processing F_2 of the low-pass filter is performed after the linear acceleration/deceleration processing according to the acceleration/deceleration system shown in Fig. 4. However, according to an acceleration/deceleration system having the acceleration/deceleration section consisting of only a low-pass filter, only the processing F_2 of Fig. 11 can be executed. In this case, Pb = Pa is established.

According to the present invention as described above, the high-frequency component is cut off by the higher-order low-pass filter, and a fast response time can be obtained. Therefore, the servo control system and its load system will not be subjected to shock, and precise control can be performed.

CLAIMS

1. An acceleration/deceleration control system of a servo motor, characterized in that a position instruction is filtered through a low-pass filter of second or higher order, thereby performing acceleration/deceleration control of the servo motor.

2. A system according to claim 1, characterized in that said low-pass filter comprises a Bessel filter.

3. An acceleration/deceleration control system of a servo motor, characterized in that a position instruction is subjected to linear acceleration/deceleration control and thereafter is filtered through a low-pass filter of second or higher order.

4. A system according to claim 3, wherein said low-pass filter comprises a Bessel filter.

FIG. 1

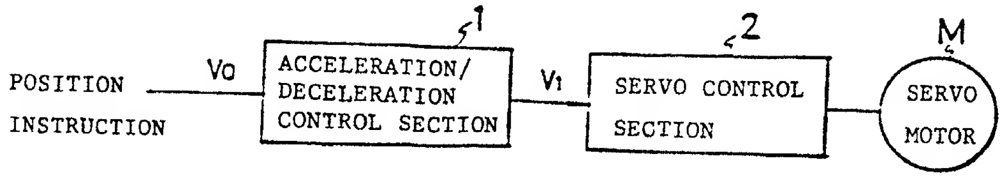


FIG. 2

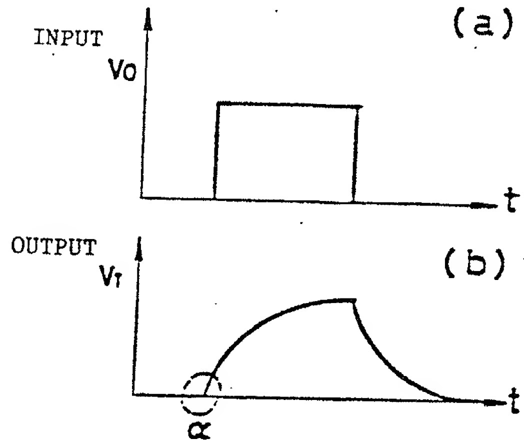


FIG. 3

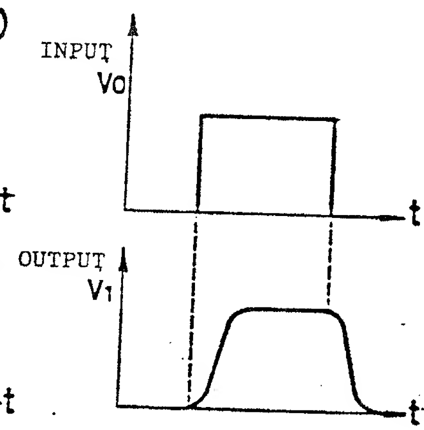


FIG. 4

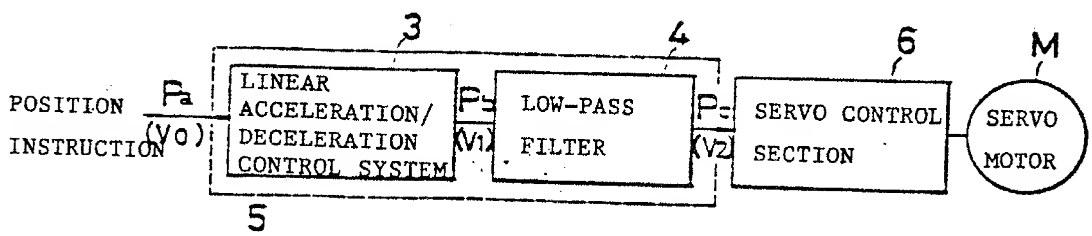


FIG. 5

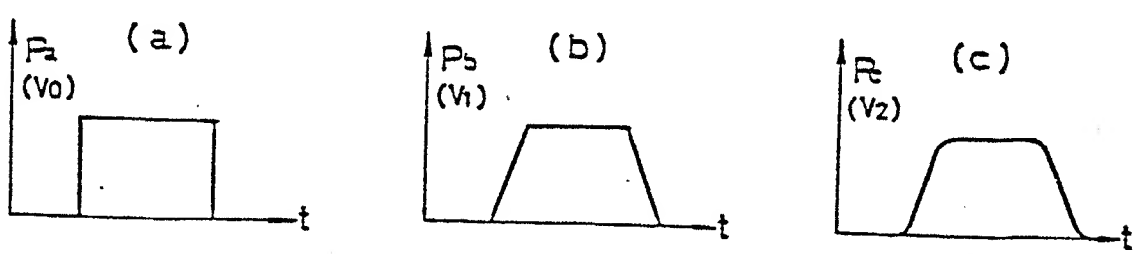


FIG. 6

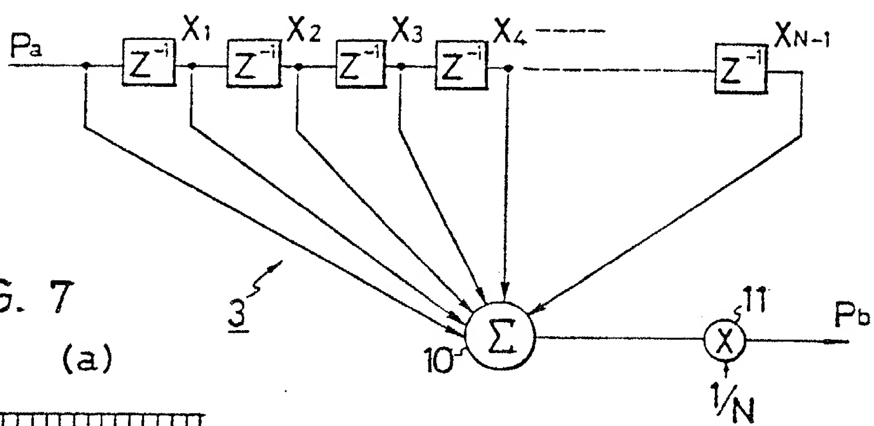


FIG. 7

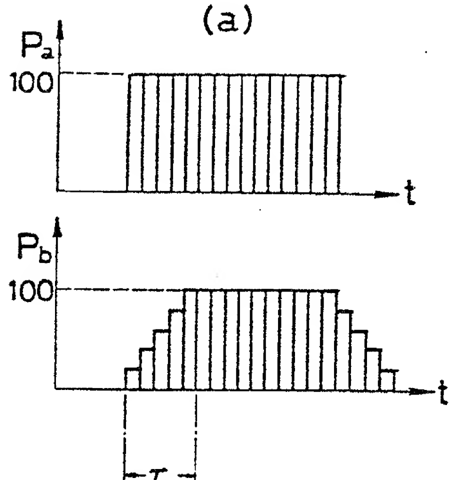
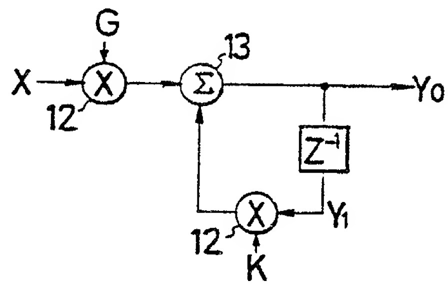


FIG. 8



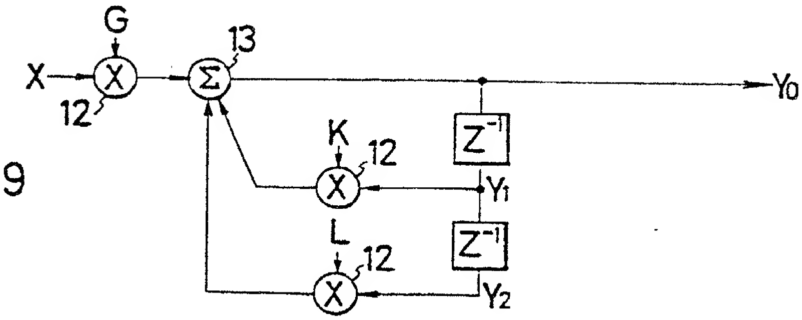


FIG. 9

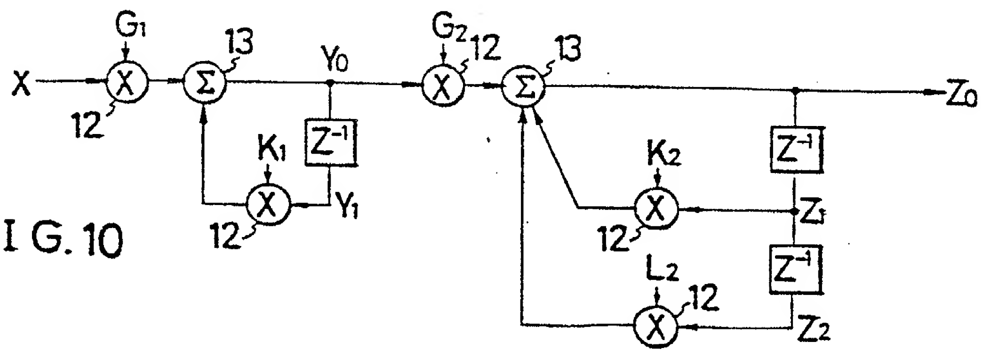
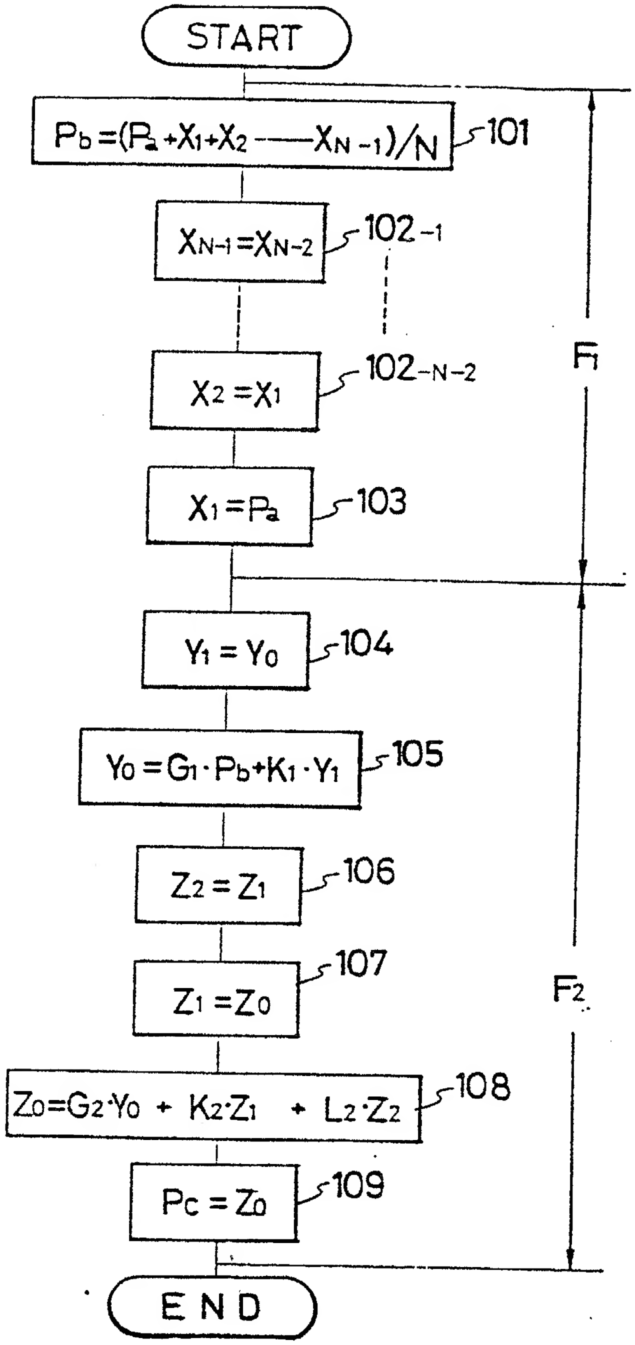


FIG. 10

FIG. 11


START
Pb=(Pa+X1+X2 ---- XN-1)/N
101
XN-1=XN-2
102-1
X2=X1
102-N-2
X1=Pa
103
F1
Y1=Y0
104
Y0=G1·Pb+K1·Y1
105
Z2=Z1
106
Z1=Z0
107
Z0=G2·Y0 + K2·Z1 + L2·Z2
108
Pc=Z0
109
F2
END

;TERNATIONAL SEARCH REPOI 0139010

International Application No. PCT/JP84/00068

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int. Cl^3 G05B 11/36, G05D 3/00

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
IPC	G05B 11/00 - 11/42, 19/00 - 19/42 G05D 3/00 - 3/14 H02P 7/00

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

Jitsuyo Shinan Koho	1960 - 1984
Kokai Jitsuyo Shinan Koho	1971 - 1984

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category*	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
X	JP, A, 48-41214 (Mitsubishi Electric Corp.) 16 June 1973 (16. 06. 73)	1 - 4
X	JP, A, 48-59316 (Toshiba Corp.) 20 August 1973 (20. 08. 73)	1 - 4

* Special categories of cited documents: [15]

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"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
May 21, 1984 (21. 05. 84)	May 28, 1984 (28. 05. 84)
International Searching Authority [1]	**Signature of Authorized Officer [20]**
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